BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W.   WASHINGTON, D. C. 20024

B70 05056

SUBJECT: Electrostatic Potential of the Lunar Communications Relay Unit S-Band Antenna - Case 340

DATE: May 22, 1970

FROM: J. L. Blank
W. R. Sill

ABSTRACT

The electrostatic potential of the Lunar Communications Relay Unit (LCRU) S-band antenna while operating will not differ much from its non-operating value. This potential is expected to lie in the range of 1 to 10 volts while the rover is on the sunlit hemisphere.

(NASA-CR-113073) ELECTROSTATIC POTENTIAL OF THE LUNAR COMMUNICATION RELAY UNIT S-BAND ANTENNA (Bellcomm, Inc.) 9 p

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MEMORANDUM FOR FILE

Introduction

The possibility has been suggested that the LCRU S-band antenna mounted on the lunar rover could charge up to a potential of about a thousand volts.(1) The potential is determined by the charge accumulation on the antenna. During non-transient operation, the antenna will assume the potential corresponding to zero net charge accumulation over any integral number of cycles. This potential can be ascertained by studying the antenna charging sources, in a manner similar to the calculation of the electrostatic potential distribution on the sunlit lunar surface by Grobman and Blank.(2)

In the present problem, there are two relevant time scales. The first is the frequency ω of the antenna. The second time scale τ is that characteristic of the charging mechanism. We can think of τ as the time it takes a representative charged particle to traverse a distance equal to the spatial extent of the antenna near electric field. As will be shown, the antenna steady state electric potential is very different according to whether $\omega\tau >> 1$ or $\omega\tau << 1$. If the antenna were able to operate with $\omega\tau << 1$ -- which it cannot -- large electrostatic potentials could exist. However, for the actual case of $\omega\tau >> 1$, the antenna signal electric field is unimportant, and the antenna potential during operation is the same as if the antenna were not operating.

Discussion

For simplicity, we assume the antenna surface is flat and situated on the sunlit lunar surface normal to the sun direction. When the antenna is not operating, it acts as an emitting dc plasma probe in the solar wind, with emission due to the production of photoelectrons by solar uv photons. The number of photoelectrons emitted per unit time is much greater than the number of electrons that can be collected from the solar wind. Thus, the antenna will charge up positively to a potential such that the escaping photoelectron flux equals the charge flux from the solar wind. Under these conditions, the dc antenna potential is a few times the average energy of a photoemitted electron, and most photoelectrons cannot escape this potential well. We can, therefore, anticipate the antenna dc potential being in the range of 1 to 10 volts. The photoelectrons form a cloud or sheath adjacent to the emitting surface. The sheath thickness is of the order of a Debye length which typically may be about 10 cm. These arguments are based on the more detailed considerations of Grobman and Blank.(2)

Figure 1 shows the dc voltage-current characteristic for a photoemitting probe in the solar wind. At large negative voltages, all the photoelectrons are repelled, while, at large positive voltages, no photoelectrons escape and the current is due to the capture of charged particles from the solar wind. At V_f, the floating probe potential, the flux of escaping photoelectrons is balanced by the solar wind flux so the net current is zero.

Now suppose we impose a slowly varying ac field on the probe, so the total potential consists of a dc component V_1 plus a time-varying component $V_2 e^{-i\omega t}$. By slowly varying we mean $\omega\tau \ll 1$, which permits us to use the dc probe characteristic. We want to determine V_1 when the net current to the probe over an integral number of cycles is zero. For the antenna, the conditions $J_{sw} \ll J_p$ and $V_f \ll V_2$ exist, where J_{sw} and J_p are defined in Figure 1 and V_f is probably less than 10 volts. For this case, it can be seen from Figure 1 that $V_1 \approx V_2$ if the net current over a cycle vanishes. Thus, the dc potential of the antenna can be as large as the amplitude of a slowly varying ac voltage.

If the antenna were able to operate at such low frequencies, a large average potential could be built up. This is not the case, though. The S-band antenna frequency is $f = 2272.5$ MHz, whereas it takes a typical photoelectron $\sim 10^{-7}$ seconds to traverse a distance equal to a wavelength or equal to the plasma sheath thickness. Thus $\omega\tau \sim 10^3 \gg 1$, and the high dc voltages theoretically possible for the slowly varying case ($\omega\tau \ll 1$) do not occur.

The potential and charge distributions depend upon the charged particle motions in the sheath. Therefore, to determine the effect of the ac antenna field, we look at the changes in the particle orbits introduced by the oscillating field. When $\omega\tau >> 1$, we expect that the perturbation introduced by the ac antenna field will average to zero over an integral number of cycles. To demonstrate that this notion is correct, we must show that a) the momentum exchange over one cycle between a representative electron and the ac field is a small fraction of the electron momentum, and b) there is no significant net electron drift motion resulting from a small perturbation per cycle adding over the large number of cycles during a photoelectron lifetime.

The ac field can be considered a small perturbation only if the fractional momentum change is small over the time $T = 1/\omega$, where $\omega = 2\pi f$. The momentum change is $\Delta p \sim eE_a/\omega$ and a representative electron's momentum is $p \sim mv_t$, where E_a is the ac electric field magnitude and v_t the electron thermal speed. Therefore, the fractional momentum change is

$$\frac{\Delta p}{p} \sim \frac{eE_a}{mv_t\omega}$$

For $\omega = 10^{10}$/sec and $v_t = 4 \times 10^6$m/sec, the electric field must be $E_a \sim 2 \times 10^5$ volts to produce $\Delta p/p \sim 1$.

We can estimate the average electric field over the dish, since the power and dish size are known and are 10 watts and 0.1 m^2, respectively. The Poynting flux is

$$S = \sqrt{\frac{\varepsilon}{\mu}}\, E_a^2 = 100 \text{ watts/m}^2$$

The average field over the dish is, then, $E_a \sim 200$ v/m, in which case we would have $\Delta p/p \sim 10^{-3}$. The electric field can be much larger near the centerfeed. For a half-wavelength diameter centerfeed, the area is 24 cm^2. This would produce an average field at the centerfeed of $E_a \sim 10^3$v/m, and the condition $\Delta p/p << 1$ is still satisfied. Therefore, the effect of the ac antenna field is small during one wave period of operation.

To look at the effect of the ac antenna field over many cycles, we treat the field as a small perturbation term in the electron equation of motion. In the Appendix, we assume a model for the ac and dc electric fields. By solving the electron equation of motion, we show that there are no long-time trajectory perturbations of magnitude greater than $\Delta p/p$. Therefore, the ac antenna field does not affect the motion of the photoelectrons.

Conclusion

The electrostatic potential of the LCRU S-band antenna, while on the sunlit lunar surface, will be the same whether or not the antenna is operating. This is because the characteristic time τ for particle motion in the photoelectron sheath surrounding the antenna is much greater than the S-band wave period, so the electrons cannot absorb power from the antenna. Since the plasma frequency is $\omega_p \sim 1/\tau$, we recognize this condition, $\omega_p/\omega << 1$, as a requisite for antenna operation. We have not considered any differences in the photoemissive properties of the antenna produced by the ac field since a large change in photoemissive properties is required to alter the physics, and such a change is highly unlikely.

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Attachments
References
Appendix
Figure 1

REFERENCES

1. T. Gold, private communication, 1970.

2. W. D. Grobman and J. L. Blank, "Electrostatic Potential Distribution of the Sunlit Lunar Surface," J. Geophys. Res., 74, 3943, 1969.

3. A. Erdélyi, Asymptotic Expansions, p. 51, Dover, New York, 1956.

APPENDIX

Here we examine the effect on a representative electron from the ac antenna field operating over many cycles. Rather than solve the plasma equations of motion together with Maxwell's equations, we shall prescribe the electric fields. We, therefore, assume

$$E = E_1 e^{-z/\lambda_1} + E_2 e^{-z/\lambda_2} e^{-i(\omega t + \phi)} \tag{1}$$

where E_1 is the electrostatic field at the antenna surface, λ_1 the spatial extent of the sheath $\sim$10 cm, E_2 the magnitude of the ac antenna field at the surface, λ_2 the characteristic length scale of the near field which is approximately the antenna dimension, and ϕ is a phase angle. The equation of motion for a photoelectron emitted normal to the antenna surface is

$$m \frac{dv}{dt} = - eE \tag{2}$$

We treat the rapidly oscillating term in (1) as a small perturbation of order $\Delta p/p \ll 1$. Then, to lowest order in this parameter, (2) has solution

$$\frac{1}{2} m \left(v_o^2 - v^2\right) = eE_1\lambda_1 \left[1 - e^{-z/\lambda_1}\right] \tag{3}$$

where we have used the initial condition $v = v_o$, $z = 0$ at $t = 0$.

The explicit time dependence is shown by integrating

$$\frac{dz}{dt} = v \tag{4}$$

where v is given by (3). The result is

$$t = \left(\frac{2\alpha^2 m\lambda_1}{eE_1}\right)^{1/2} \left[\sec^{-1}\alpha - \sec^{-1}\left(\alpha e^{-z/2\lambda_1}\right)\right] \tag{5}$$

where

$$\alpha = \left(1 - \frac{mv_o^2}{2eE_1\lambda_1}\right)^{-1/2} \tag{6}$$

For the first iteration, we use (5) in (1). The equation of motion in this approximation is

$$m\frac{dv}{dt} = mv\frac{dv}{dz} = -eE_1e^{-z/\lambda_1} \tag{7}$$

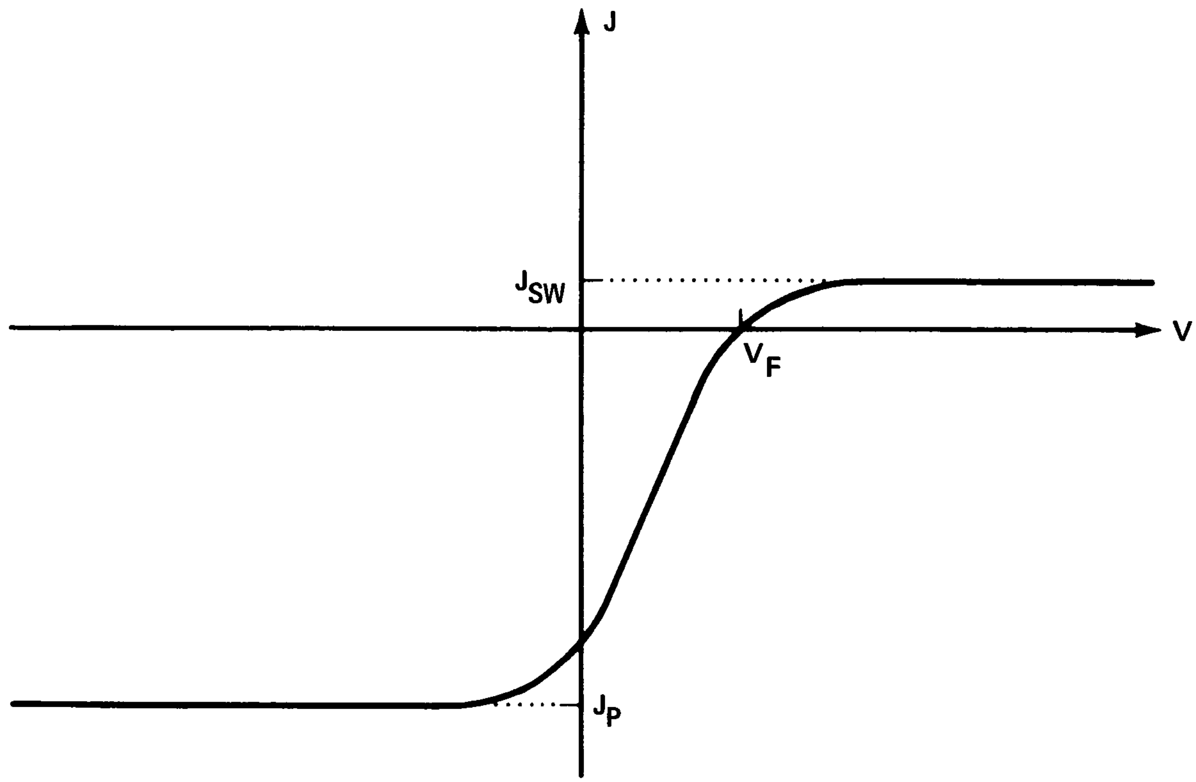
$$-eE_2e^{-z/\lambda_2} \exp\left\{-i\omega\left(\frac{2\alpha^2 m\lambda_1}{eE_1}\right)^{1/2}\left[\sec^{-1}\alpha - \sec^{-1}\left(\alpha e^{-z/2\lambda_1}\right)\right]\right\}e^{-i\phi}$$

Upon integrating, we find

$$\frac{1}{2}m\left(v_o^2 - v^2\right) = eE_1\lambda_1\left[1 - e^{-z/\lambda_1}\right] \tag{8}$$

$$+ eE_2e^{-i\phi}\int_0^z dz'e^{-z'/\lambda_2} \exp\left\{-i\omega\left(\frac{2\alpha^2 m\lambda_1}{eE_1}\right)^{1/2}\left[\sec^{-1}\alpha - \sec^{-1}\left(\alpha e^{-z'/2\lambda_1}\right)\right]\right\}$$

The integral in (8) can be evaluated by the method of stationary phase. Following Erdélyi,[3] we can show that the integral has no stationary phase and, therefore, that the dominant contribution comes from the end points. But by the arguments presented in the Discussion, the contribution from the end points is of order $(\Delta p/p)\frac{1}{2}mv_o^2$. Thus the perturbation due to the ac antenna field is small.



$J_{SW} \sim 10^8\ (CM^2\text{–}SEC)^{-1}$ IS THE RANDOM SOLAR WIND FLUX

$J_P \gtrsim 10^{10}\ (CM^2\text{–}SEC)^{-1}$ IS THE TOTAL PHOTOEMITTED ELECTRON FLUX

FIGURE 1. VOLTAGE CURRENT CHARACTERISTIC FOR A PHOTOEMITTING PROBE IN THE SOLAR WIND

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